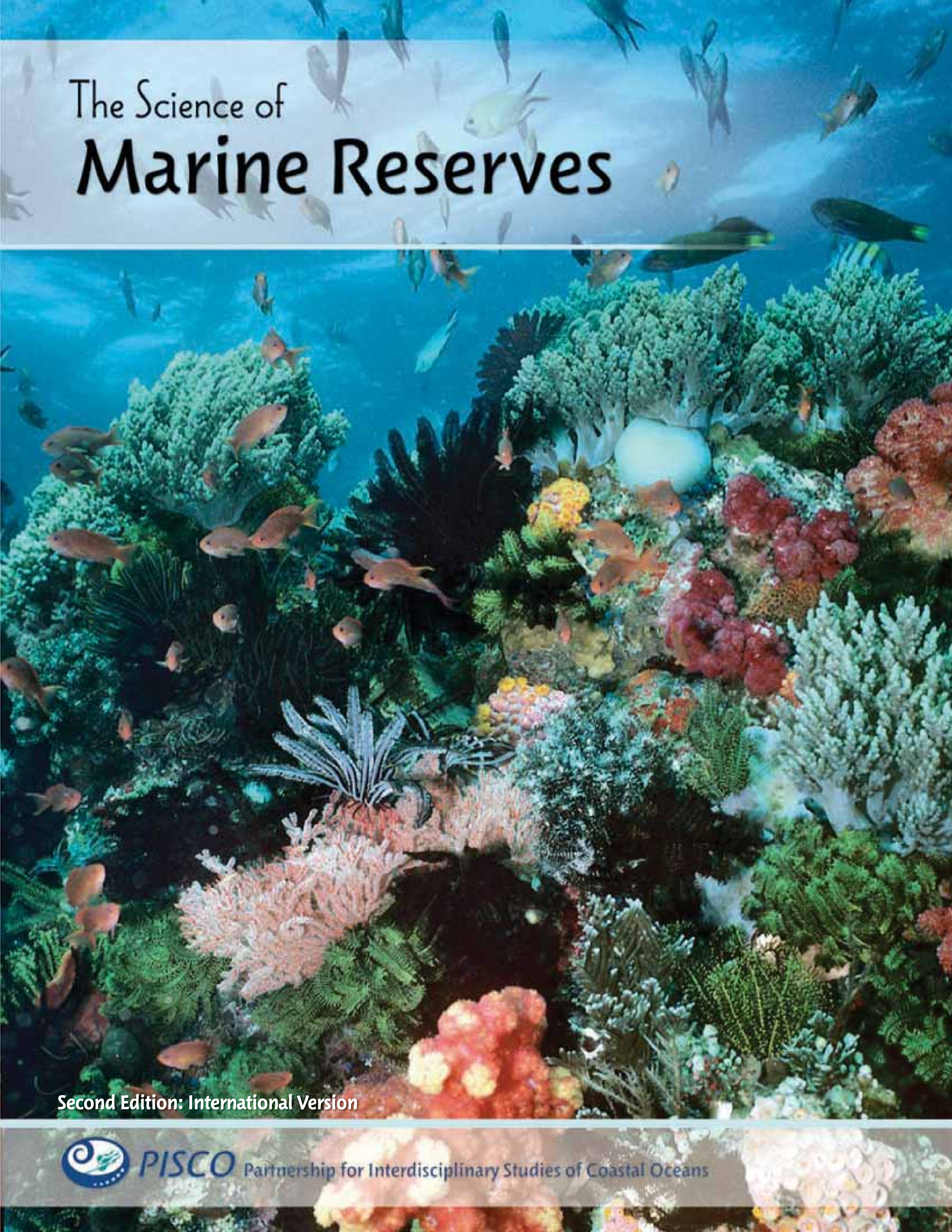
The Science of
# Marine Reserves



Second Edition: International Version

PISCO Partnership for Interdisciplinary Studies of Coastal Oceans

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PISCO is a consortium of academic scientists at Oregon State University; University of California, Santa Barbara; University of California, Santa Cruz; and Stanford University. PISCO advances the understanding of coastal marine ecosystems and communicates scientific knowledge to diverse audiences.

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## Table of Contents

# Overview:

**Oceans** around the world are becoming degraded. Evidence shows that human activities are altering ocean ecosystems beyond their natural range of variability. According to numerous scientific studies, fish, shellfish, and other species are declining in many places. The changes are impairing the ocean's capacity to provide food, protect livelihoods, maintain water quality, and recover from environmental stress. These and other benefits, collectively called **ecosystem services**, depend on healthy ecosystems.

Many people are inquiring about solutions to reduce negative impacts and foster ocean health and resilience. Increasingly, government agencies, commercial groups, non-government organizations, the public, and scientists are discussing the idea of establishing marine reserves to complement other efforts to restore and sustain ocean ecosystems.

***Marine reserves are defined as ocean areas that are fully protected from activities that remove animals and plants or alter habitats, except as needed for scientific monitoring.*** Examples of prohibited activities are fishing, aquaculture, dredging, and mining; activities such as swimming, boating, and scuba diving are usually allowed. Marine reserves receive permanent protection, rather than seasonal or short-term protection. Because marine reserves protect habitats and the diversity of animals and plants that live in those habitats, marine reserves are a form of ecosystem protection that produces different outcomes from other management tools. As with any form of management, a marine reserve is only effective if its protection is enforced.

Many other kinds of marine protected areas (MPAs) exist. However, they exclude only some human activities that harm animals, plants, and habitats. Those MPAs may provide some benefits, but they do not produce the same outcomes as marine reserves because they do not provide the same comprehensive level of protection.

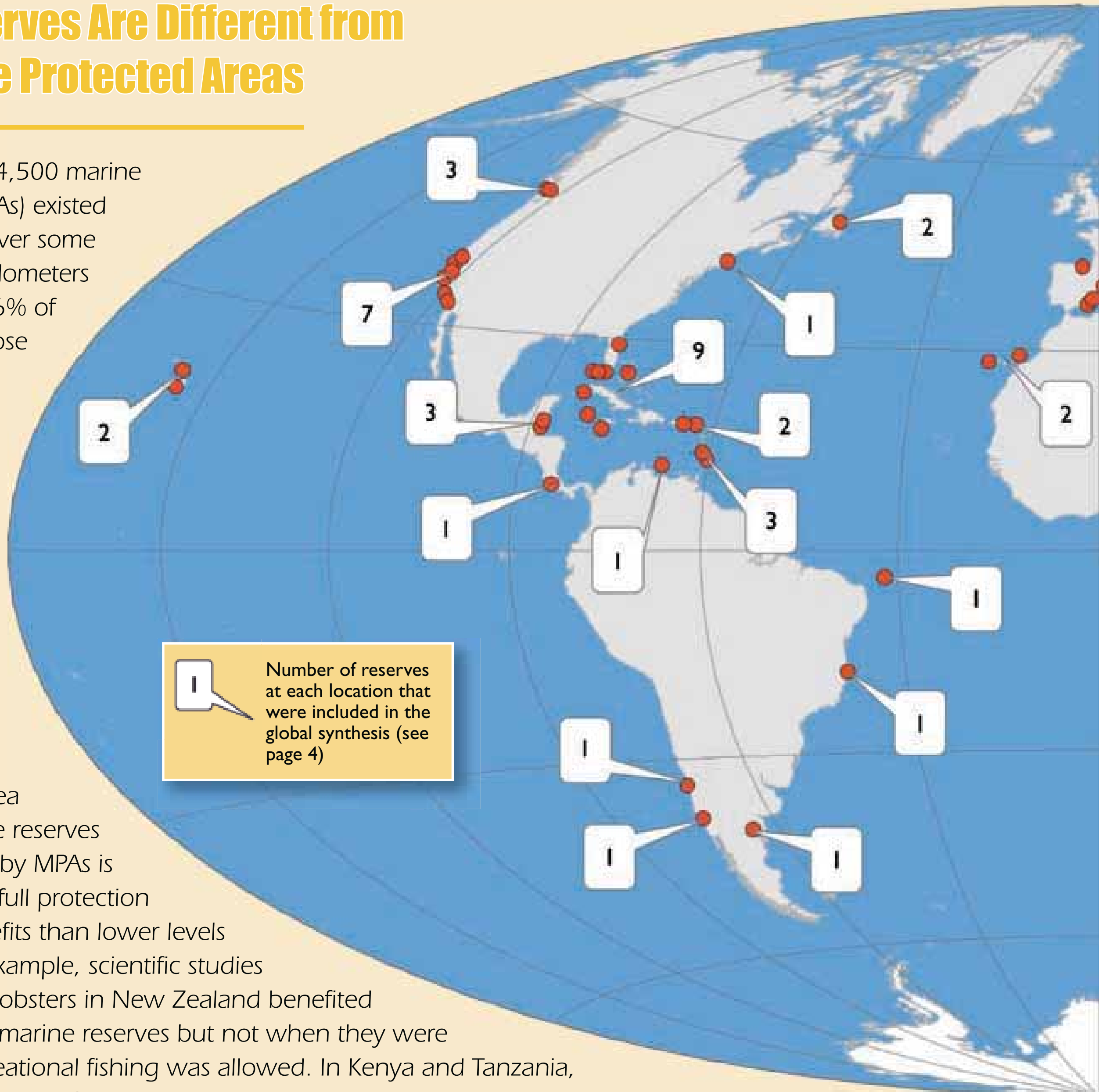
Although marine reserves can be an effective tool, reserves alone cannot address problems such as pollution, climate change, or overfishing. Other management strategies are needed along with the creation of marine reserves.

This booklet summarizes the latest scientific information about marine reserves, including case studies from around the globe. Scientific evidence shows that marine reserves usually boost the abundance, diversity, and size of marine species living within their borders. Science can explain how these changes occur and provide useful information for designing marine reserves.

# what is a marine reserve?

## Marine Reserves Are Different from Other Marine Protected Areas

As of 2006, at least 4,500 marine protected areas (MPAs) existed worldwide. They cover some 2.2 million square kilometers or approximately 0.6% of the ocean. Of all those MPAs, only a small number are marine reserves, which receive complete and permanent protection. Less than 36,000 square kilometers of the ocean, or 0.01%, is currently protected in marine reserves.





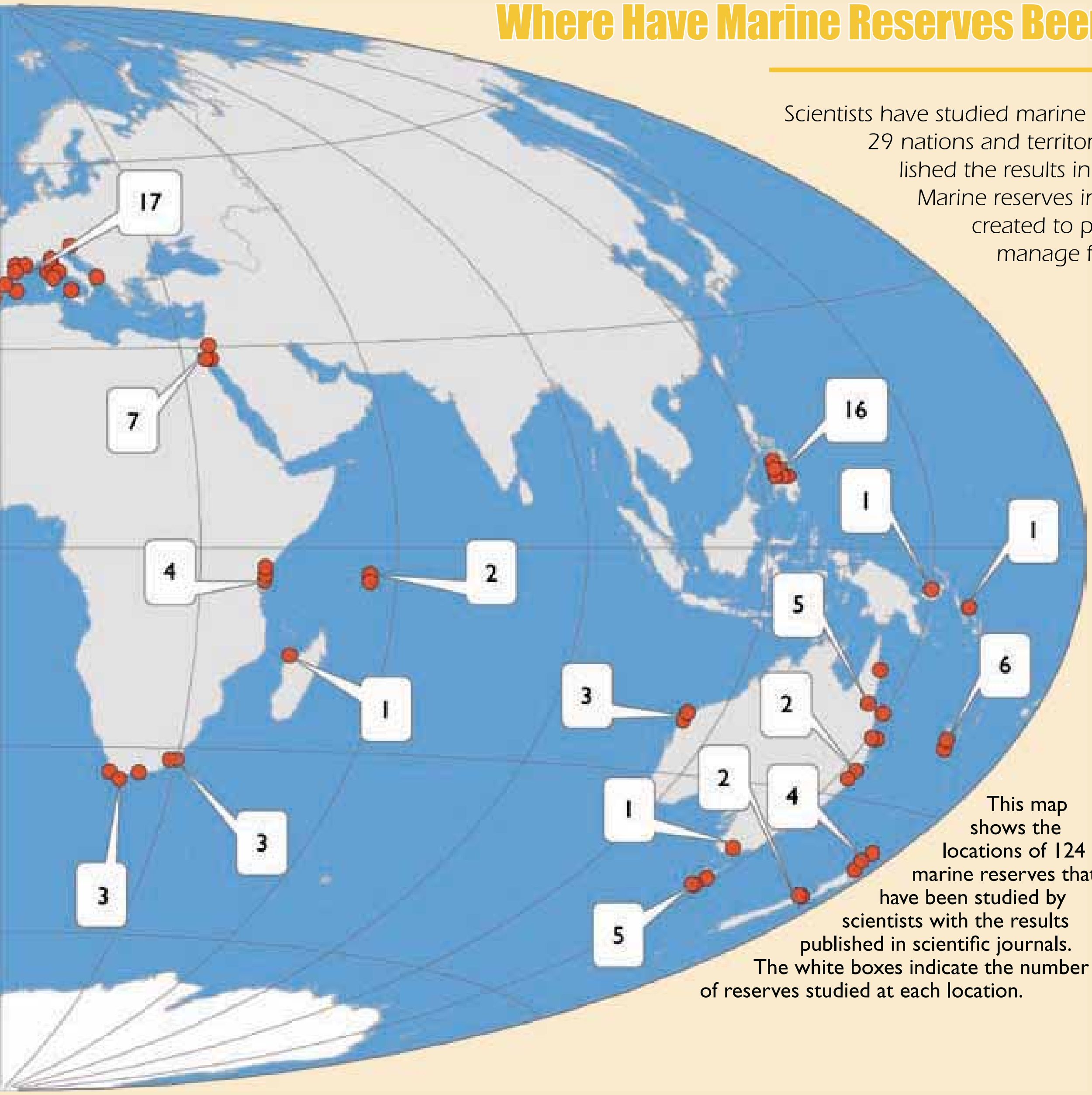

The difference in area protected by marine reserves and area protected by MPAs is significant because full protection provides more benefits than lower levels of protection. For example, scientific studies demonstrated that lobsters in New Zealand benefited when they were in marine reserves but not when they were in MPAs where recreational fishing was allowed. In Kenya and Tanzania, marine reserves sustained fish biodiversity and delicate corals, but management areas that permitted fishing did not.

People sometimes think that temporarily closed areas, or rotational closures, might provide the benefits of marine reserves without the drawbacks of permanent closure. Traditional rotational closure of no-take areas can be culturally important and result in sustainable fisheries in some contexts. However, studies in areas such as Hawaii, Iceland, and the Philippines showed that opening areas to fishing led to rapid loss of the benefits gained from long-term protection. It can take only a year or two to deplete fish and shellfish populations that accumulated over decades inside marine reserves. Certain species and habitat types, such as long-lived animals and coral reefs, may take decades or centuries to recover from human exploitation.

# marine reserves studied around the world

# Where Have Marine Reserves Been Studied?

Scientists have studied marine reserves in at least 29 nations and territories and have published the results in scientific journals. Marine reserves in these areas were created to protect biodiversity, manage fisheries, or restore marine species.




This map shows the locations of 124 marine reserves that have been studied by scientists with the results published in scientific journals. The white boxes indicate the number of reserves studied at each location.

- Argentina
- Australia
- Bahamas
- Barbados
- Belize
- Brazil
- Canada
- Canary Islands
- Chile
- Costa Rica
- Cuba
- Egypt
- France
- Grand Cayman
- Israel
- Italy
- Jamaica
- Kenya
- Netherlands Antilles
- New Caledonia
- New Zealand
- Papua New Guinea
- Philippines
- Saint Lucia
- Seychelles
- Solomon Islands
- South Africa
- Spain
- United States

## Global Marine Reserve Facts

- **Marine reserves cover less than 0.01% of the ocean worldwide.**
- **Scientists have studied at least 124 marine reserves and published the results in scientific journals. Marine reserves in the studies ranged from 0.006 to 800 square kilometers.**
- **Most reserves are quite small. Half of the 124 reserves studied by scientists covered less than 3.75 square kilometers.**
- **A survey of 255 marine reserves showed that only 12 were patrolled routinely to prevent poaching.**

*References: 2, 3, 4, 5, 6, 26*

# effects of marine reserves inside their borders

Typically when a marine reserve is established, the goal is to increase the abundance and diversity of marine life inside. Scientific research shows that marine reserves consistently accomplish this goal.

## More Fishes, Shellfish, and Other Marine Life

Considerable scientific documentation—published in peer-reviewed journals—provides a clear picture of what has happened after the establishment of marine reserves.

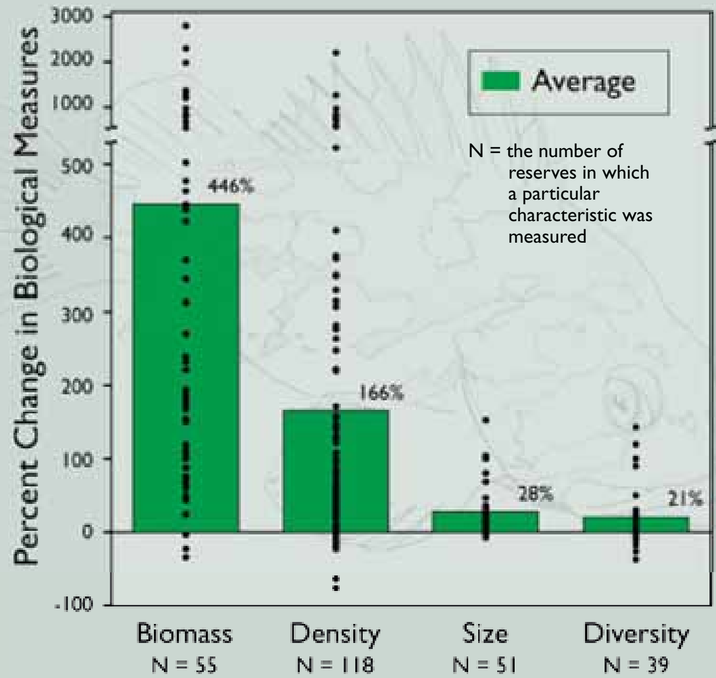
Scientists have studied more than 124 marine reserves around the world and monitored biological changes inside the reserves.

The number of species in each study ranged from 1 to 250.

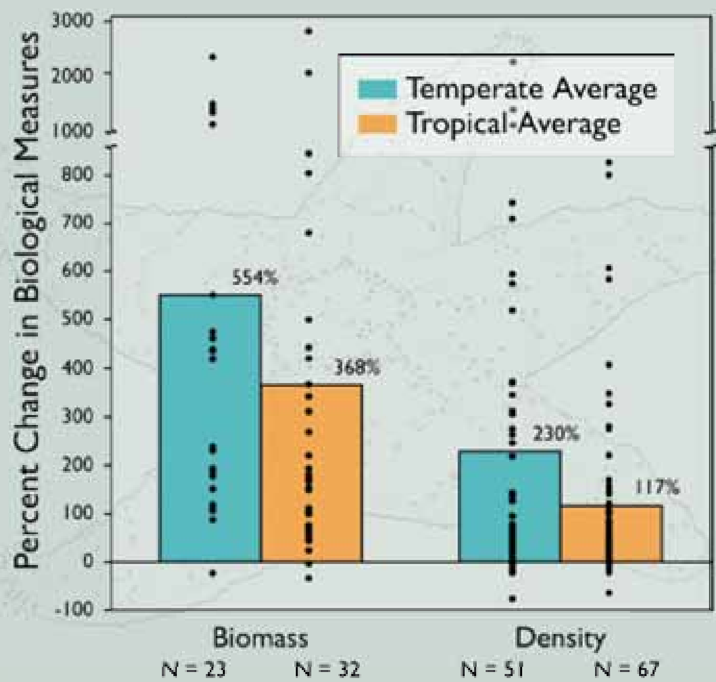
As indicated in the top graph, the studies documented a wide range of changes inside marine reserves, but nearly all of the effects were positive. A global review of the studies revealed that fishes, invertebrates, and seaweeds had the following average increases inside marine reserves:

1. **Biomass,** or the mass of animals and plants, increased an average of 446%.
2. **Density,** or the number of plants or animals in a given area, increased an average of 166%.
3. **Body size** of animals increased an average of 28%.
4. **Species diversity,** or the number of species, increased an average of 21% in the sample area.

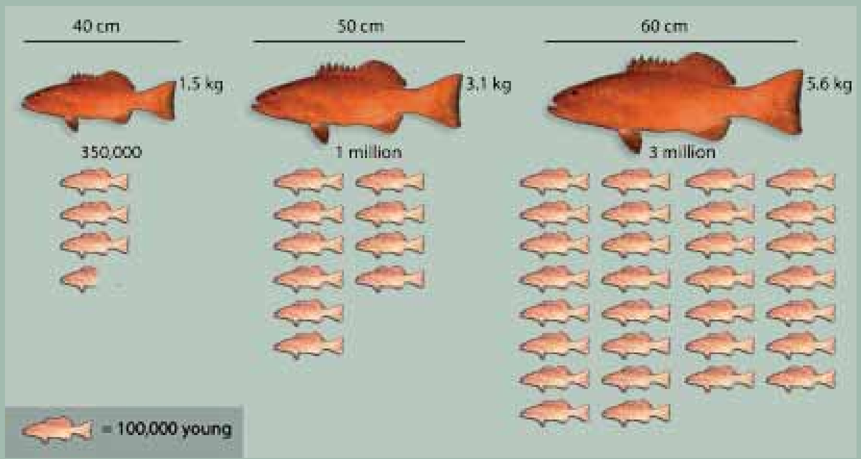
Heavily fished species often showed the most dramatic increases. Some fished species had more than 1000% higher biomass or density inside marine reserves. Even small changes in species diversity and individual body size are important; these values have less potential for change than biomass or density.




Average changes (green bars) in fishes, invertebrates, and seaweeds within marine reserves around the world. Although changes varied among reserves (black dots), most reserves had positive changes. *Data: Ref. 8*




Average changes in fishes, invertebrates, and seaweeds within marine reserves from temperate (blue bars) and tropical (orange bars) regions around the world. Although changes varied among reserves (black dots), most reserves had positive changes in both regions. *Data: Ref. 8*




Average numbers of young produced by three different sizes of coral trout.

## Small Reserves Can Be Effective

*Marine reserves included in peer-reviewed scientific studies have ranged in size from 0.006 to 800 square kilometers. A global scientific review showed that some species can benefit from small marine reserves. If managed well, even small reserves can produce benefits that are distributed to local people, helping to ensure compliance with the no-take rules. However, small reserves by themselves will not protect the bigger populations, more species, and more habitat types that are found in large marine reserves.*

## Reserves Have Been Effective in Tropical and Temperate Waters

*A global scientific review showed that biological increases happened in both tropical and temperate reserves. Increases in biomass, density, body size, and diversity were similar between tropical and temperate reserves (see bottom figure, opposite page). Biomass especially increased dramatically in both temperate and tropical reserves. These findings show that marine reserves can be effective regardless of latitude.*

## Species May Increase, Decrease, or Not Change

*Although there tend to be large overall increases in biomass, density, size, and diversity inside marine reserves, some individual fish and invertebrate species may become more plentiful, while others decline or do not change. In general, species subject to fishing in unprotected waters tend to increase in marine reserves. A worldwide analysis found that 61% of fish species were more abundant inside reserves than outside, while 39% of species were more abundant outside reserves than inside (see figure, right).*

*Some fish and invertebrate species become less abundant in an area after it is designated as a marine reserve. Such declines generally reflect interactions among species, such as larger numbers of a predator eating more of its prey. For example, sea urchins may decline if a key predator, lobster, increases inside a marine reserve.*

*Similar increases in predators and decreases in prey have been documented inside marine reserves in California, New Zealand, The Bahamas, Australia, and Chile. These results suggest that natural biological interactions can be protected inside marine reserves.*

*References: 7, 8, 9, 10, 11, 12, 13, 29, 36*

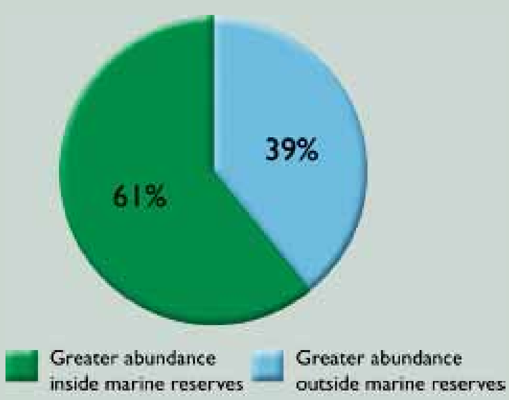
### Bigger Fish Have More Young

*Fishes and invertebrates grow bigger in marine reserves than in unprotected areas. This effect of marine reserves is extremely important because these large animals contribute much more to the next generation. They produce substantially more babies than small fishes and invertebrates. For example, a 60-centimeter coral trout produces 10 times more young than when it was 40 centimeters long (see figure, left). Bigger and more abundant animals living in a marine reserve can produce far more young than their smaller neighbors in unprotected waters.*

### Fast Facts

- Fishes, invertebrates, and seaweeds typically have grown 28% bigger and have become 166% more abundant inside marine reserves.
- On average, diversity has increased 21% and biomass has increased 446% inside marine reserves.
- Both temperate and tropical marine reserves have been effective.
- The bigger fishes and invertebrates in marine reserves can produce more young than smaller animals outside reserves.
- In existing marine reserves, many species increased, particularly those that were fished, and some species decreased, such as those that are prey to fished species.

### Fish Responses in Marine Reserves




A worldwide analysis showed that fishes varied in their responses after establishment of marine reserves. *Data: Ref. 13*

## How Long Does It Take to See a Response?

Although some changes happen rapidly, it may be decades before the full effects of a marine reserve are evident. Some fishes, shellfish, and other species may not change noticeably in abundance, body size, biomass, or diversity for some time. The following traits influence the response time after a reserve is established:

- The availability of breeding adults
- How fast individual plants and animals grow
- The age at which animals and plants can reproduce
- The number and timing of young produced by each female
- Characteristics during each life stage, such as young staying within the reserve versus dispersing outside
- Interactions among species, such as predators and prey
- Human impacts prior to reserve establishment, such as the intensity of fishing or amount of seabed damage from dredging
- Continuing impacts from outside, such as pollution and climate change
- The habitat's ability to recover after being damaged
- The level of enforcement used to prevent poaching inside the reserve

A graysby grouper in the Florida Keys.
*Photo: Evan D'Alessandro*

### Fast Facts

- Inside marine reserves, fast-growing fishes and invertebrates that mature quickly and produce many young are likely to increase most rapidly, sometimes within 1 to 2 years.
- Slow-growing fishes and invertebrates that mature at an older age and produce few young may increase slowly inside a reserve over years or decades.
- Some ecological changes may not be evident in a marine reserve for years after an area is protected.
- Long-term protection and monitoring are necessary to reveal the full effects of marine reserves.

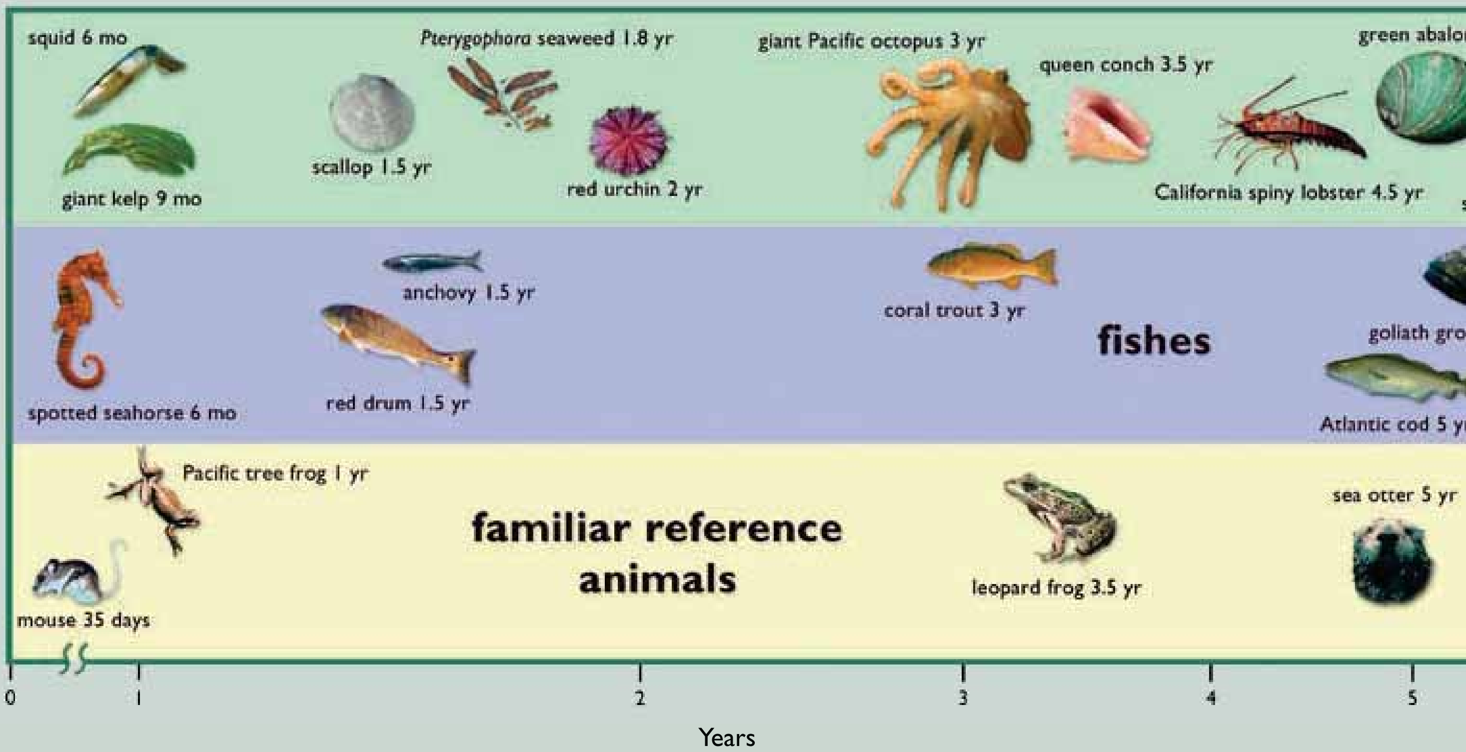
## Species Grow and Mature at Different Rates

Fishes and invertebrates vary greatly in how fast they grow and in the age when they can first reproduce (see figure below). These traits influence the response of each species after a marine reserve is established.

Some species—such as scallops—grow quickly, mature at a young age, and produce large numbers of young. These animals may multiply rapidly in a marine reserve and become much more abundant within 1 to 2 years.

Other species—such as rockfish, grouper, and humphead wrasse—grow slowly and mature at an older age. These slow-growing species are particularly vulnerable to overfishing. They may take many years to increase noticeably in a reserve.

## Age of Maturity for Selected Species

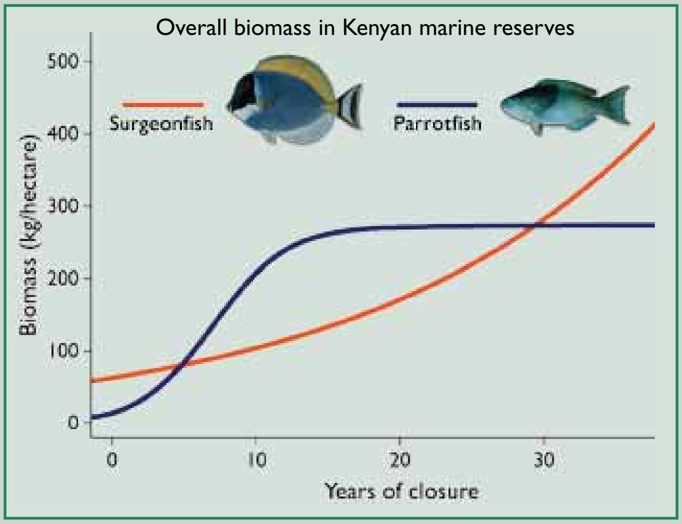


## Changes Inside Marine Reserves Occur at Different Times

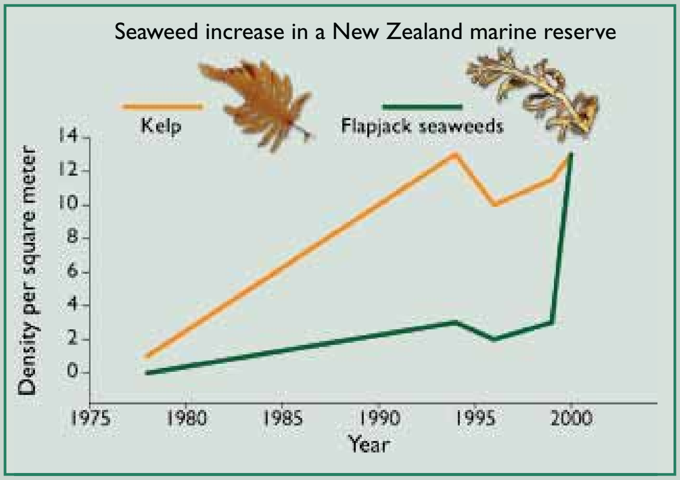
*Among the factors affecting the response times of fishes, invertebrates, and seaweeds are differences in their age at maturity, mating behavior, how many young they produce, their interactions with other species, their mobility, and the type of habitat in which they live.*

*Long-term monitoring programs at marine reserves in Kenya, the Philippines, and New Zealand have shown that animals with long life spans can take decades to fully recover after they are protected. In Kenya, for example, scientists monitored 4 marine reserves through 37 years of closure. As shown in the graph at right, the scientists found that total biomass of long-lived surgeonfish species (red line) was still increasing slowly and continuously even after nearly 4 decades. Shorter-lived parrotfish species (blue line) in these same reserves responded more quickly and then leveled off within 20 years.*

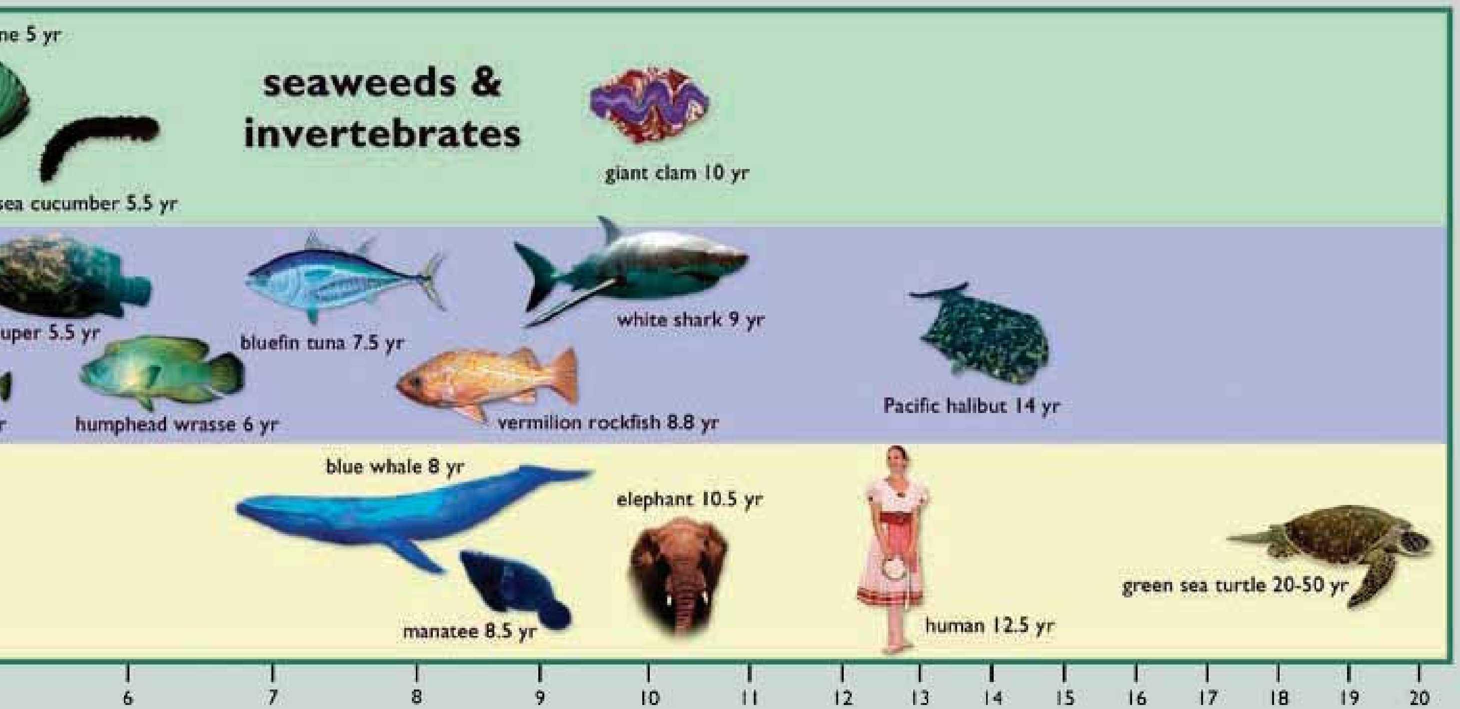
*In New Zealand, 2 types of brown seaweeds responded differently to protection in Leigh Marine Reserve. At mid-depths, the increase in kelp was relatively rapid after the reserve was established in 1978 and then leveled off (see figure at right). Flapjack seaweeds took much longer to respond at these same depths, reaching comparably high densities only after 22 years. One reason for the different responses is that kelp thrives at mid-depths, while flapjack seaweed grows more vigorously in shallow water. By 2000, kelp was 12.5 times more abundant and flapjack seaweed was 28.5 times more abundant inside Leigh Marine Reserve than in fished areas. Properly evaluating the effects of the marine reserve on these seaweeds required monitoring of both species at a range of depths for 2 decades.*




Increases in surgeonfish species (red line) and parrotfish species (blue line) in 4 Kenyan marine reserves. *Data: Ref. 16*




Inside Leigh Marine Reserve in New Zealand from 1978 to 2000, kelp (orange line) increased more rapidly than flapjack seaweeds (green line) at mid-depths. *Data: Ref. 29*




*References: 14, 15, 16, 29*

# Case Study: Kisite Marine National Park, Kenya

A reef scene at Kisite Marine National Park in Kenya. *Photo: Robert Tillner*

A butterflyfish at Kisite Marine National Park. *Photo: Tim McClanahan*


Kisite Marine National Park, Kenya, and Mtang'ata Collaborative Management Area, Tanzania

## A Marine Reserve Boosts Abundance

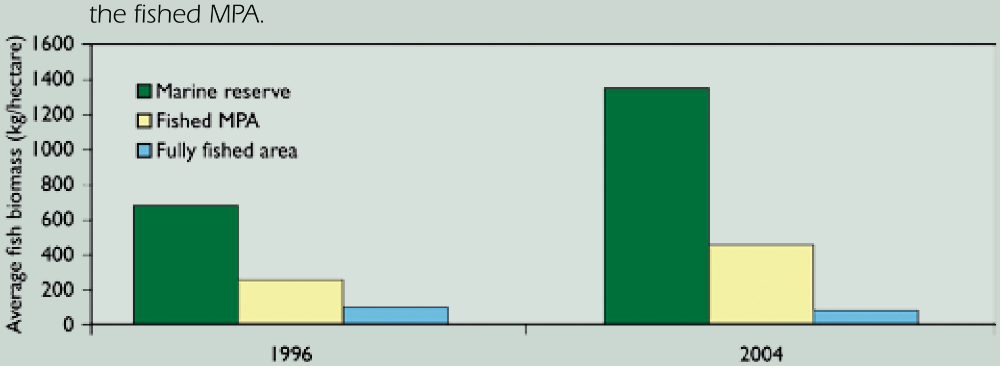
In 1973, Kenya established Kisite Marine National Park in an area of coral reefs along its southern coast. In the 1990s, authorities began to enforce rules that prohibited fishing, and the park became a marine reserve.

Across the border in Tanzania, local government in 1996 created Mtang'ata Collaborative Management Area, a marine protected area (MPA). This fished MPA is not a marine reserve, but regulations and enforcement have dramatically reduced the use of destructive fishing practices, such as dynamite fishing, poison fishing, beach seining, and dragging of nets.

Biologists conducted surveys of fish, coral, and seaweeds in 1996 and 2003-2004. The study assessed the effectiveness of the Kisite marine reserve and the Mtang'ata fished MPA by comparing similar types of habitat at both locations with each other and with nearby unprotected reefs.

The scientists determined that reduced use of destructive fishing gear in the fished MPA had successfully increased fish stocks and had kept ecological diversity the same over the 8-year period. However, the site had fewer fish species overall than the marine reserve and did not adequately protect sensitive, branching corals because some fishing still occurred. At the marine reserve, scientists found that fish biomass was 2.8 times greater than at the fished MPA and 11.6 times greater than in fully fished areas. The marine reserve also had higher fish diversity, with an approximate total of 10 more fish species per area sampled than the fished MPA. Overall, both protected areas had more fish and biodiversity than unprotected areas.

This study demonstrates that the fished MPA provided some protection to fished stocks, but the marine reserve produced greater ecological benefits than the fished MPA.




A marine reserve in Kenya (green) had more fish biomass than a fished MPA at a comparable site in Tanzania (yellow) and surrounding waters that are open to fishing (blue). *Data: Ref. 26*

*Reference: 26*

### Lessons Learned

- Fish biomass inside a marine reserve was 11.6 times higher than in fully fished areas and 2.8 times greater than in a fished MPA.
- The marine reserve had greater biodiversity and provided better protection for branching corals than the fished MPA or the fully fished areas.

A Kenyan fishing boat. *Photo: Tim McClanahan*

# Case Study: Leigh Marine Reserve, New Zealand

A spiny lobster and its sea urchin meal in the Leigh Marine Reserve. *Photo: Nick Shears*

A snapper in the Leigh Marine Reserve. *Photo: Nick Shears*


Leigh Marine Reserve, New Zealand

## Marine Reserve Sustains Web of Life

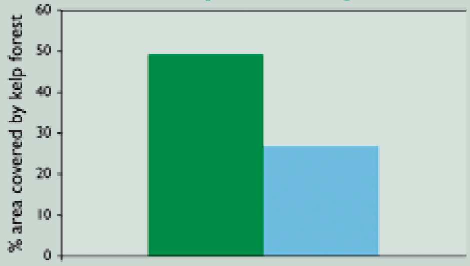
The Leigh Marine Reserve in New Zealand was established in 1975, making it one of the oldest marine reserves in the world. It includes rocky reefs from the shoreline to depths of more than 10 meters along the North Island.

In the 1970s, much of the region's seafloor was barren. Shallow kelp forests, which provided habitat for numerous animals, had been destroyed by grazing sea urchins. Nearly 30 years later, a scientific study found that kelp beds had recovered dramatically in the marine reserve, covering most of the seafloor. Fully fished areas outside, however, were still mostly barren.

Kelp forests now flourish inside the marine reserve because lack of fishing has allowed predatory fishes and lobsters to rebound there. The fishes and lobsters eat sea urchins, which graze on kelp. Snappers have become 8.7 times more abundant and spiny lobsters 3.7 times more abundant in the marine reserve than in the outside fished areas. An experiment testing survival of urchins (see graph below) showed that the abundant snappers and lobster predators in the marine reserve have kept the urchin population in check, allowing kelp to grow.

Outside the marine reserve, where fishing occurs, predatory snappers and lobsters are scarce, enabling urchins to increase in number quickly. Even a mass die-off of urchins did not allow kelp forests to recover outside the reserve.

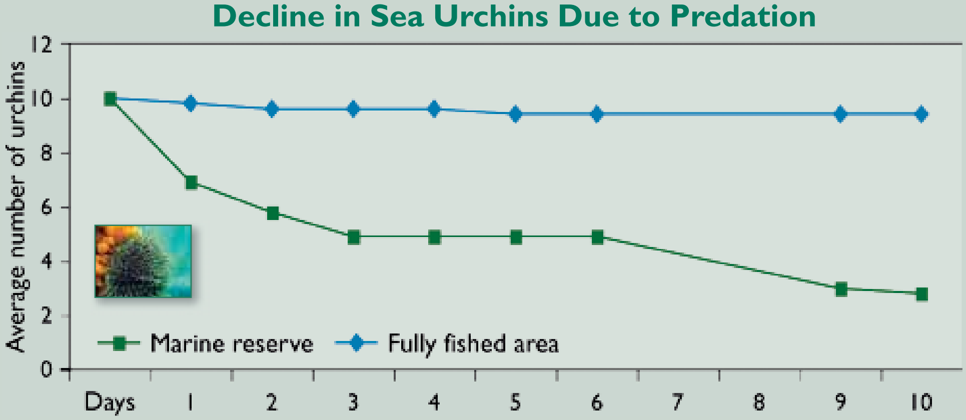
### Kelp Coverage




### Urchin Barren Coverage


Leigh Marine Reserve had more healthy kelp forests, and fished areas outside the reserve had more urchin barrens. *Data: Ref. 29*

### Decline in Sea Urchins Due to Predation




During a ten-day experiment, fewer urchins survived in the marine reserve than outside. Numbers of their snapper and lobster predators are higher in the reserve because fishing is prohibited. *Data: Ref. 28*

### Lessons Learned

- Inside the marine reserve, 8.7 times more snapper and 3.7 times more lobsters led to flourishing kelp forests because these predators ate kelp-eating urchins.
- Outside the marine reserve, urchins were so abundant that even a decrease in their numbers after a mass die-off did not restore kelp forests.

*References: 27, 28, 29*

# effects of marine reserves beyond their borders

A marine reserve's effects on fishes, invertebrates, and other species are most apparent inside the reserve. However, these impacts may extend to unprotected areas outside. Boosts in growth, reproduction, and biodiversity in a marine reserve can replenish fished areas when young and adults move out of the reserve.

**Fast Facts**

- Some adult and juvenile animals swim outside marine reserves to unprotected waters.
- Young animals may drift out from marine reserves into fished areas.

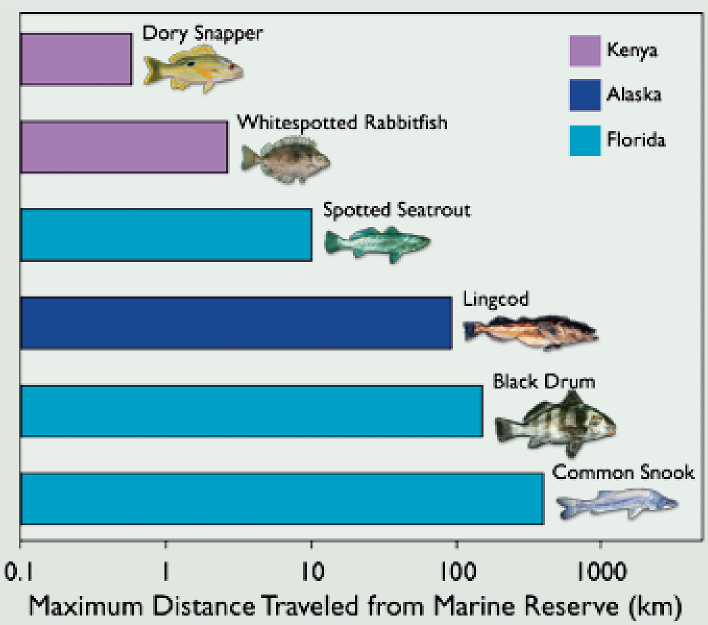


## Movement of Adults and Juveniles

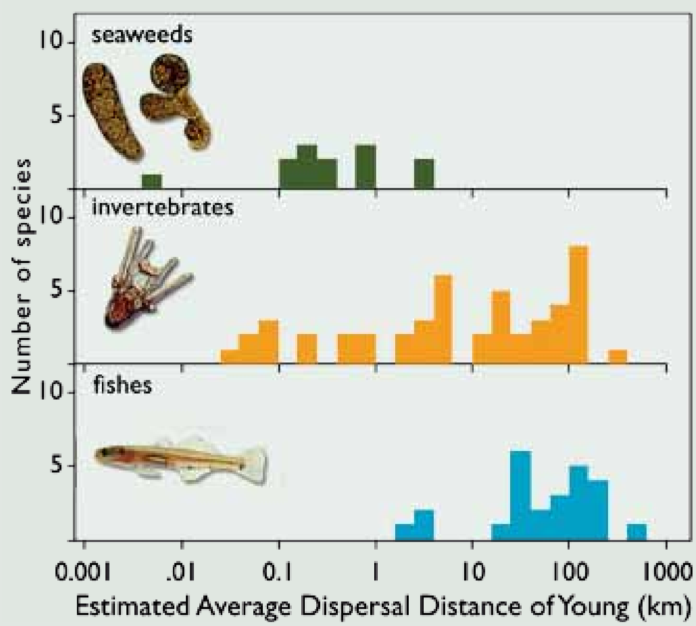
As fishes and invertebrates become more abundant inside a marine reserve, some adults and juveniles may leave the marine reserve to live elsewhere. They also may leave because they need a different habitat as they grow or because they reproduce in a specific place outside the reserve. The spillover of adult and juvenile fishes and invertebrates can contribute to marine populations living in fished waters outside reserves. Scientists have documented spillover from marine reserves in the United States, The Bahamas, Saint Lucia, Kenya, the Philippines, Australia, New Zealand, and the Mediterranean Sea.

## Movement of Young

Fishes and invertebrates typically release huge numbers of tiny young into the open ocean. They can stay there for days or months, potentially traveling far from their origin. Some young produced in a marine reserve may remain inside, while others may settle far away from the reserve. Through this export of young, animals in marine reserves can help replenish populations in outside waters. Scientists are using genetic data, life-cycle information, computer models, and advanced tagging techniques to learn how many young are exported from marine reserves and where they go.




This graph shows the maximum distances that tagged fishes traveled from marine reserves in Kenya (violet), Alaska (navy), and Florida (turquoise). These studies provide direct evidence that fishes spill over from marine reserves into surrounding waters. *Data: Ref. 19, 24, 25*



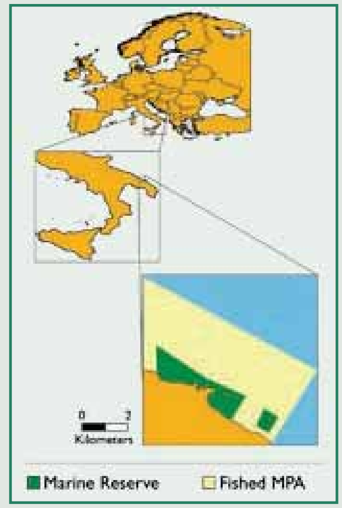

The estimated average distances traveled by young invertebrates (51 species), fishes (26 species), and seaweeds (13 species) prior to settling at their adult homes. Distances are based on genetic analysis of species around the world. *Data: Ref. 33*

*References: 17, 18, 19, 20, 21, 22, 23, 24, 25, 33, 34*

# Case Study: Torre Guaceto Marine Reserve, Italy

A sea bream, a commercially important fish, inside Torre Guaceto Marine Reserve. *Photo: Egidio Trainito*

The tower at Torre Guaceto. *Photo: Paolo Guidetti*




Torre Guaceto Marine Reserve, Italy

## Fish Move Outside a Marine Reserve

Torre Guaceto Marine Reserve is located in southeastern Italy in the Adriatic Sea. The reserve was established in 1992, but effective enforcement began a few years later. Within a decade, the reserve had 2 times as many sea bream, an important commercial fish, as a comparable area outside the reserve.

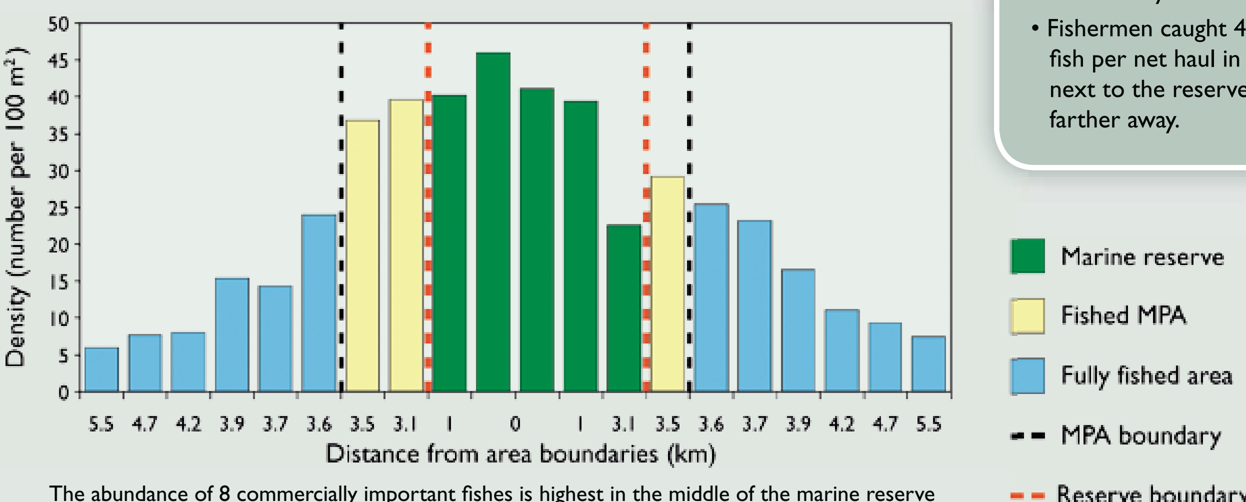
In 2004, scientists found evidence that fishes from the marine reserve were spilling over into fished waters nearby. Eight commercially important fishes were most abundant in the middle of the reserve (green bars, graph below). These fishes declined near the reserve's boundary along a fished marine protected area (MPA, yellow bars), and they declined farther outside the protected areas in fully fished areas (blue bars). This gradient in abundance suggests that adult fishes produced in the reserve moved into unprotected areas, where fishermen could catch them.

Surrounding Torre Guaceto Marine Reserve, fishermen have used low-impact techniques in a fished MPA since 2004. Working with scientists, they selected fishing gear that minimizes harm to the underwater habitats, and they agreed to fish only once a week. Since 2004, the commercial catch per unit effort from this area was 4 times higher than in fully fished areas. This is likely a result of both the spillover from the borders of the marine reserve (indicated in the graph below) and the low-impact fishing methods. Because the fishermen have seen benefits for their fishery, many of them now support both the marine reserve and the fished MPA.

Fishermen use low-impact methods outside Torre Guaceto's marine reserve. *Photo: Dario Fiorentino*

### Lessons Learned

- Adult fishes of 8 commercially important species appeared to move from the marine reserve, where they were most abundant, into nearby fished waters.
- Fishermen caught 4 times more fish per net haul in a fished MPA next to the reserve than they did farther away.




The abundance of 8 commercially important fishes is highest in the middle of the marine reserve and declines beyond the reserve boundary in a fished MPA and a fully fished area. *Data: Ref. 30*

*References: 30, 31*

# scientific considerations for designing marine reserves

***Marine reserves are intricately connected with human society and economics. As scientists learn more about marine ecosystems and human interactions with the ocean, analyses suggest that reserves work best when ecological, social, and economic considerations are all factored into the design plans. In general, creating reserves involves a series of tradeoffs that must be balanced to meet the goals. For example, a large reserve might be ecologically optimal but economically or institutionally impractical. Commonly asked questions about designing marine reserves include:***

- ***Where should reserves be located?***
- ***How big should reserves be?***
- ***How many reserves should be in an area?***
- ***How close together should reserves be?***

North West Island, part of the Great Barrier Reef in Australia. *Photo courtesy of the Great Barrier Reef Marine Park Authority*



## Reserve Design Depends on the Goals

A successful design for a set of marine reserves depends on clearly stated goals. Clearly defined goals are important because they influence critical decisions about how to design marine reserves.

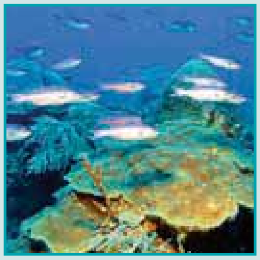
Although ecological goals often are viewed as being in conflict with some social and economic goals, recent research suggests that the choice is not between environmental and economic goals but rather between short-term gain and long-term prosperity. Long-term gains depend directly on healthy and resilient ecosystems.

Consequently, one important goal for creating marine reserves is to protect or restore an ocean ecosystem, enabling it to provide ecosystem services on a sustainable basis. These ecosystem services include seafood production, good water quality, control of pests and pathogens, coastal protection, and climate regulation (see page 16). Other important goals for marine reserves are to maintain fishing lifestyles and incomes, provide recreational and cultural opportunities, minimize disruption of human uses of the ocean, and provide places for education and research.

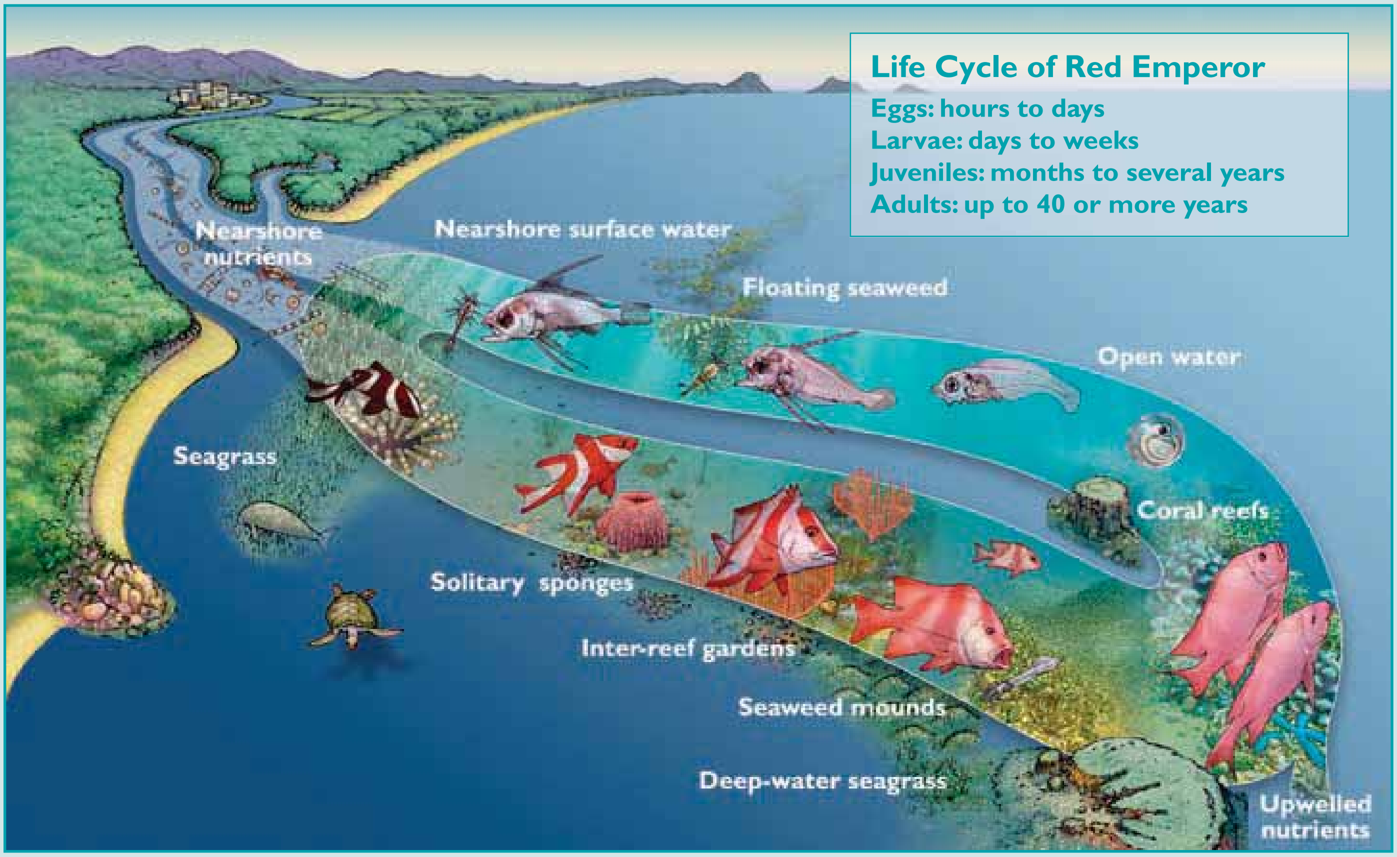
## The Role of Reserve Networks

Sometimes it is more economically sustainable to establish several marine reserves instead of one big reserve in a particular area. For example, in some regions it might not be feasible to include a portion of each habitat in a single marine reserve without disrupting human activities. In such cases, ecological benefits can be maximized by creating multiple reserves that are close enough together to act as a network. In a marine reserve network, young and adults traveling out of one reserve may end up being protected in another reserve. Marine reserve networks provide more protection than a set of individual, unconnected reserves.




*Photos: Cristine McConnell, Tim McClanahan, U.S. Geological Survey, Jiangang Luo, Patricio Manriquez*




A red emperor uses many habitats throughout its life. Open water, floating seaweed, seagrass, sponges, and coral reefs are important for growth and survival during different life stages of this fish. *Image courtesy of Russell Kelley*



## Ocean Ecosystems Depend on Connected Habitats

*In the ocean, habitats are connected through movement of animals and plants and through exchange of nutrients. Most marine fishes and invertebrates use more than one habitat during their lives, making them vulnerable to many human impacts.*

*The red emperor, a fish that lives in the western Pacific Ocean and the Indian Ocean, provides an example of how a species uses more than one habitat (see figure above). As adults, red emperors live near coral and rocky reefs, often swimming over sand flats and gravel patches. Their young hatch into the open ocean, where they may live for 20 to 40 days. Small juveniles inhabit turbid coastal waters, mangroves, and reefs. As they age, red emperors move offshore into depths of 10 to 100 meters, often forming schools. Some adults migrate into shallow waters during the winter months.*

*To thrive from birth through old age, red emperors need many habitats—open ocean, shallow seagrass and sponges, inter-reef gardens and seaweed mounds, and deep-water reefs and seagrass. If one habitat is not available, the life cycle cannot be completed. Other marine species have similar requirements for multiple habitats over the course of their lives.*

*Consequently, when marine reserves are intended to protect even just one or a few species, they must include parts of all habitats used by those species, which often means protecting some of all habitats in the general area. When the goal is to protect many species, it is essential for all habitats to be represented in marine reserves.*

### Fast Facts

- Most marine fishes and invertebrates use more than one habitat during their lives.
- Each habitat is home to a special group of animals and plants.
- When the goal of a marine reserve is to protect many species, all habitats used by these species throughout their life must be included.

A juvenile red emperor takes refuge in the spines of a sea urchin. *Photo: J. E. Randall*

*References: 1, 32, 34, 35*

# Considerations for Individual Marine Reserves

## Where Should a Marine Reserve Be Located?

Once it is decided to establish a marine reserve—or more than one—in a region, the next decision is where to put it.

Scientific considerations for locating marine reserves include the following:

- Different habitat types in the region
- Oceanographic features, such as linkages created by ocean currents
- Important places for species of interest, such as vulnerable spawning grounds
- Locations inhabited by rare or geographically restricted species
- Prior habitat damage and potential for recovery
- Vulnerability to natural and human impacts, including those from which marine reserves do not offer protection, such as pollution
- Location of human activities such as fishing, tourism, transportation, scientific research, and cultural resources
- Perceptions and preferences of local communities and policy makers
- Socio-economic impacts and opportunities provided by a reserve

The weight given to each of these factors varies with the reasons for establishing the marine reserve. For example, if a goal is to support the general health of the marine ecosystem in order to benefit local communities, marine reserves need to protect some of all habitats found in each oceanic region and accommodate human uses of the ocean in the surrounding area.

Some fish species, such as Nassau grouper (above), gather at spawning grounds each year, where they are especially vulnerable to overfishing. Such vital spawning areas, often located at seamounts or reef headlands, can be protected in marine reserves. *Photo: Enric Sala*

### Fast Facts

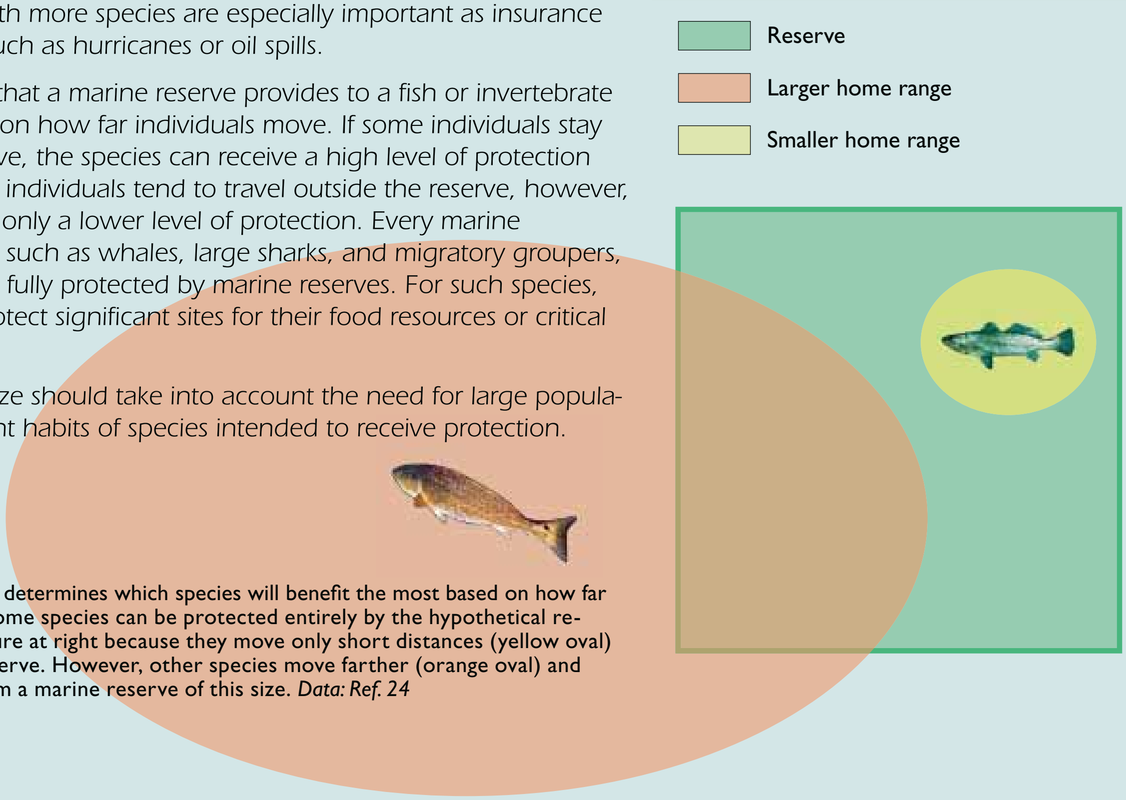
- A small marine reserve can provide some benefits, but by itself it will not be able to protect large populations of many different species.
- A large marine reserve can have a greater effect because it includes more habitats and more wide-ranging species.
- Reserve size and patterns of animal movement determine the level of protection that a marine reserve provides to each species.

## How Big Should a Marine Reserve Be?

Scientific studies show that even small marine reserves can have positive impacts on the abundance, biomass, body size, and biodiversity of animals and plants within their boundaries. However, a bigger marine reserve can protect more habitat types, more habitat area, bigger populations of animals, and a larger fraction of the total number of species in an ecosystem. Bigger populations in areas with more species are especially important as insurance against catastrophes, such as hurricanes or oil spills.

The level of protection that a marine reserve provides to a fish or invertebrate species depends partly on how far individuals move. If some individuals stay entirely inside the reserve, the species can receive a high level of protection (see graphic at right). If individuals tend to travel outside the reserve, however, the species can receive only a lower level of protection. Every marine ecosystem has animals, such as whales, large sharks, and migratory groupers, that move too far to be fully protected by marine reserves. For such species, marine reserves can protect significant sites for their food resources or critical parts of their life cycle.

The choice of reserve size should take into account the need for large populations and the movement habits of species intended to receive protection.




The size of a marine reserve determines which species will benefit the most based on how far the adults move. Adults of some species can be protected entirely by the hypothetical reserve (green box) in the figure at right because they move only short distances (yellow oval) and may never leave the reserve. However, other species move farther (orange oval) and would likely benefit less from a marine reserve of this size. *Data: Ref. 24*

# Considerations for Marine Reserve Networks

## How Many Reserves Should There Be?

In many places, a single marine reserve that is large enough to protect all habitats may be impractical because of geography or the possibility of initial socioeconomic impacts. For example, a large reserve might cause longer travel to fishing sites at greater cost. As a result, the preferred option may be an ecological network of several small- or medium-sized marine reserves in a region, rather than one or two large reserves.

Establishing a network of several smaller marine reserves can be a viable alternative to meet established goals while reducing the negative impacts of a single large reserve.

Networks are most effective when each type of habitat is represented in more than one reserve, and when individual reserves are big enough and close enough to protect adults and young. Reserve networks can provide insurance because a catastrophe that harms populations and habitats in one marine reserve may not affect other reserves. The unaffected marine reserves can help replenish nearby populations damaged by a catastrophe.

A major socioeconomic benefit of a network is that fishing and other human activities can occur between the reserves instead of being excluded from one large area. Young fishes and invertebrates generally are not vulnerable to fishing, so at least a portion may disperse safely among the reserves, providing a source of young for reserves and fished areas outside.

## How Close Together Should Reserves Be?

If a group of marine reserves is to function as a network, the reserves must be close enough to connect with each other through movement of animals. Enough of the abundant young fishes and invertebrates that leave one reserve should be able to settle into another to ensure sustainable populations. When several reserves are placed in an ecosystem so that they are ecologically connected by dispersal of young or adults, they protect the ecosystem better than if they were unconnected.

Marine species vary tremendously in how far they move. For many coastal species, the young, called larvae or propagules, move farther than adults. Consequently, a reserve network may be designed so that individual reserves are large enough to accommodate the movement of adults, while spacing among reserves accommodates the longer-distance movement patterns of young.

Young that travel short distances may stay inside the reserve where they were born. Other young are likely to end up outside. Reserves that are more closely spaced can be ecologically connected and protect a greater fraction of species through movement patterns of young.

### Fast Facts

- A network of several smaller marine reserves can be a viable alternative to one large reserve.
- A network can function to protect multiple habitats and species and to provide insurance against catastrophes.
- To form a network, reserves should be spaced closely enough that young fishes and invertebrates can move among them.

### A Marine Reserve Network


Part of a network of marine reserves (green) and fished MPAs (yellow) established along the central coast of California in 2007.

*Photos: Peter H. Taylor, Sergio Hoare, Steve Lonhart*

*References: 33, 34, 36, 37*

# People and Marine Reserve Design

## Human Dimensions

The socioeconomic costs and benefits of marine reserves influence their planning, design, and eventual outcomes. Broader policy issues, such as the relationship between marine reserves and other tools for ocean governance, also play an important role. For example, reserves alone cannot protect ocean biodiversity or fisheries if unsustainable fishing occurs in waters outside marine reserves.

Social scientists have begun to identify the social and economic factors that enhance the success of marine reserves:

- ***Clear goals***
- ***Supportive institutions and legislation***
- ***High participation in community decision-making***
- ***Involvement of people with diverse interests***
- ***Effective use of scientific advice***
- ***Effective conflict-resolution mechanisms***
- ***Sustainable finance***
- ***Initiatives to provide fishermen with alternate income***
- ***Equitable sharing of economic benefits***
- ***Fair enforcement***

Increased attention to the human dimensions of marine reserves and ocean governance will be necessary to ensure effective management over the long term.

### Quick Summary

- Marine reserves can help sustain valuable services provided by ecosystems.
- People are important players in the ocean ecosystem. They have many different viewpoints that can be incorporated into the design of marine reserves.
- Community involvement, education, enforcement, and long-term funding are crucial for the success of marine reserves.
- Marine reserves can generate economic benefits.

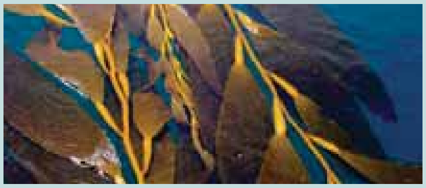
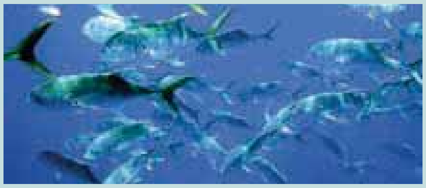
*Photos clockwise from upper left: Annalise Hagan, Jane Lubchenco, © Great Barrier Reef Marine Park Authority, Steve Clabuesch, Freya Sommer, Ernesto Weil*



## What Are Ecosystem Services?





People—even those who live far from the sea—depend on ocean and coastal ecosystems for their survival and well-being. Benefits produced by ecological systems are called ecosystem services. Examples of ecosystem services provided by the ocean and coast include: seafood production; climate regulation; recycling of nutrients; control of pests and diseases; protection of coasts from erosion; removal of excess nutrients coming from the land; and provision of recreation, inspiration, and cultural heritage.

Coastal ecosystems provide essential services, but they suffer some of the most intense human impacts. People often take these ecosystem services for granted and do not recognize how the impairment or loss of these services can affect their communities.

For example, towns and cities can become more vulnerable to natural catastrophes such as hurricanes and flooding when urbanization degrades salt marshes, mangrove forests, coral reefs, kelp forests, barrier islands, and other natural features that normally offer protection from storms. By protecting some of all marine habitats and species in one place, marine reserves can help to sustain the ecosystem services that humans want and need.

*References: 1, 35, 36, 37*

# People and Marine Reserve Design

## How Do People Influence the Planning and Design of Marine Reserves?

Marine reserves can be designed to accommodate many people's viewpoints while still achieving conservation and management goals. The following are important human factors to consider:

A man in Papua New Guinea shows off his catch. *Photo: Joshua Cinner*

### No-take Recreation

Marine reserves can be ideal for non-consumptive recreational activities, such as sightseeing, scuba diving, and snorkeling. Participants in these activities and the tourism industry can help select locations for marine reserves. Care must be taken to ensure that recreational activities do not damage sensitive plants, animals, and habitats.

### Existing Patterns of Human Activities

Maps showing where human activities—such as fishing, aquaculture, seabed mining, and energy production—occur in the ocean can be used to reduce the potential negative effects of marine reserves on people's lives and the economy.

### Cultural Values

Sometimes marine reserves can protect areas of historical, cultural, or spiritual significance. Historians and cultural experts should be consulted to determine how marine reserves could help achieve this goal.

### Compliance and Enforcement

A marine reserve should be designed to facilitate compliance and enforcement, which are critical for success. Whenever possible, the boundaries should be easily recognizable, such as headlands, islands, or other landmarks onshore, or lines of latitude and longitude offshore. Enforcement may be easier if a ranger station or government office is nearby. To encourage compliance, managers should involve stakeholders to gain their support.

### Monitoring

Monitoring ecological, social, and economic changes associated with marine reserves is critical to determine if management goals are being achieved. Scientists and managers can collaborate to plan and implement monitoring programs.

### Long-term Support

Ecological benefits that build up over decades can be wiped out in a year or two if a marine reserve is not maintained and enforced. Long-term arrangements for funding, management, and other support are essential.

Snorkelers at Lamont Reef, part of the Great Barrier Reef. No-take tourism has a gross estimated value of $589 million annually, which is greater than the $381 million estimated value of all fisheries in this area. *Photo courtesy of the Great Barrier Reef Marine Park Authority Data: Ref. 40*

### Economic Impacts

The economic impacts of marine reserves are complex because they differ by site and business sector. Because marine reserves protect valuable ecosystem services that otherwise may be lost, a well-designed and -enforced network of marine reserves could generate an overall long-term economic benefit.

After a marine reserve is established, fishing revenues may drop in the short term unless catches in another area can compensate. In a matter of years, the growth and reproduction of fishes and invertebrates in a marine reserve may boost fishing revenues.

Alternative income opportunities can result from increases in local tourism.

Some marine reserves draw sightseers, kayakers, scuba divers, and other tourists, who add money to the local economy. For example, a study showed that most dive operators in 30 Latin American and Caribbean countries took their clients to marine protected areas. These divers paid more than $1 billion annually in user fees.

*References: 35, 36, 37, 38, 39, 40, 42*

# science and the process of planning marine reserves

## What Role Can Science Play?

Establishing marine reserves usually involves people with diverse backgrounds in resource use, marine policy, natural and social science, business, conservation, and ocean recreation. These people can use traditional knowledge and scientific information about habitats, species diversity, human uses, and other topics to make informed decisions about marine reserves. In addition to this information, decision-makers usually weigh trade-offs among people's short- and long-term goals, costs and benefits for the functioning of ecosystems, economics, and community values.

An analysis of marine reserve planning demonstrates that clear goals, effective use of scientific advice, and participation of multiple groups affect reserve success. The following 3 case studies are examples of different ways in which science has provided information for people involved with creating marine reserves in diverse social and economic situations around the world.

### Lessons Learned

- Science can be used to make informed decisions about marine reserves.
- Involvement of stakeholders is vital for design, management, and enforcement of marine reserves.
- Support from local government is critical for long-term effectiveness of marine reserves.

## Case Study: Great Barrier Reef Marine Park, Australia



Created in 1975, the Great Barrier Reef Marine Park covers 344,400 square kilometers along Australia's northeastern coast. From the early 1990s, there were concerns that the existing zoning did not adequately protect the range of biodiversity known to exist throughout the Marine Park. Furthermore, the location of most marine reserves at that time reflected a historical focus on coral reef habitats, with an emphasis on the more remote and pristine areas.

Recognizing the importance of using the best available science, the federal Great Barrier Reef Marine Park Authority worked with scientists to identify 70 unique bioregions. Then they established 2 groups to define guiding principles for development of a new zoning plan:

1. A Scientific Steering Committee developed 11 biological and physical principles, including a minimum amount of protection needed for each different biological region.
2. A Social, Economic, and Cultural Steering Committee developed 4 principles to maximize positive impacts and minimize negative impacts on Marine Park users and other interest groups.

Specially designed computer software was used to evaluate zoning options that met the biological and physical targets. The Authority considered over 31,000 public comments and information about human uses and values to refine the draft zoning plan. The goal was to achieve the biophysical principles and minimize the potential negative social and economic impacts.

In 2004, the Australian Parliament approved the final plan that included marine reserves encompassing more than 33 percent of the Marine Park. The well-defined scientific guidelines and the careful consideration of public interests contributed to the successful planning process.

Northeastern Australia, where the Great Barrier Reef Marine Park is located.

An aerial view of Lizard Island in the Great Barrier Reef Marine Park. *Photo courtesy of the Great Barrier Reef Marine Park Authority*

*References: 35, 37, 41, 42, 43*

## Case Study: California, USA

The Marine Life Protection Act, signed into state law in 1999, requires California to design and manage a network of marine reserves and other marine protected areas (MPAs) to protect marine ecosystems and marine natural heritage. In 2004, the California Resources Agency used state and private funding to launch the Marine Life Protection Act Initiative, which during its first phase implemented the Act along the central coast of California. The Initiative brought together 3 groups of volunteer advisors:

1. A Blue Ribbon Task Force of distinguished and knowledgeable public leaders guided the process and formulated a master plan.
2. Groups of stakeholders identified regional goals and created different possible designs for the MPA network.
3. A Science Advisory Team provided scientific information, developed guidelines for MPA design to meet goals set by law, and evaluated proposed MPAs in terms of scientific guidelines and potential socioeconomic impacts. The scientists presented information about marine science to provide all participants with a scientific foundation for decision-making.

The Blue Ribbon Task Force encouraged the stakeholders to adhere to the Science Advisory Team's guidelines for MPA design. In an iterative process, the stakeholders developed potential designs for an MPA network, and the scientists recommended adjustments based on the scientific criteria. The state regulatory agency decided to implement 29 marine protected areas along the state's central coast. These protected areas include 14 marine reserves that cover 7.5 percent of waters within 4.8 kilometers of the coast.

The coast of California, which is the focus of the Marine Life Protection Act Initiative.

Waves break at Big Sur on the central California coast. *Photo: Steve Lonhart*

## Case Study: Apo and Sumilon Islands, Philippines

Apo Island and Sumilon Island are 2 marine reserves in the Philippines. The reserve at Apo Island has been protected continuously for 24 years. Sumilon has had a complex history of management due to changes in local governance.

The reserve at Sumilon Island was established in 1974 after biologists and social scientists from Silliman University set up a marine conservation program on a nearby island. Science contributed to the reserve process when scientists and residents discussed basic marine ecological concepts, and the idea of creating a marine reserve evolved. A local government ordinance established the Sumilon Marine Reserve.

Full protection of the Sumilon Marine Reserve has been temporarily suspended 2 times since 1974 for political reasons. Fish abundance decreased sharply when the area was opened to fishing. After full protection was reinstated, the number of fish gradually increased again.

On Apo Island, scientific education programs sparked residents' interest in protecting and managing marine resources. The local municipality and Silliman University collaborated to establish Apo Marine Reserve in 1982. The reserve has been protected for over 20 years through the joint efforts of the fishing community, local government, and university.

Scientific studies in the Apo and Sumilon Marine Reserves have provided an unparalleled, long-term understanding of biological changes in marine reserves. These results show that reserves can lead to increases in abundance, size, and biomass and that they can benefit the surrounding fisheries. These reserves have provided economic benefits to the local communities by increasing tourism and associated revenues.

The Philippines, where Apo and Sumilon Islands are located.

A coral hind takes shelter in a reef at the Apo Island Marine Reserve. *Photo: Brian Stockwell*

# summary: marine reserves contribute to ocean health

**_Scientific evidence clearly shows that people are causing a decline in the ocean's health. Marine reserves have proved to be an effective way to protect habitats and biodiversity in the ocean. While marine reserves are not a cure-all, they are important for sustaining ocean life and human well-being._**

## People Have Created Marine Reserves Around the World

At least 45 nations—ranging from small islands to large countries—have established marine reserves in temperate and tropical regions. Scientific studies of at least 124 marine reserves in 29 nations have been published in peer-reviewed journals. Data from these studies allow reliable conclusions about the effectiveness of marine reserves. Although numerous marine reserves have been established, they cover less than 0.01% of the world's oceans.

## Marine Reserves Help to Sustain Ocean Life

Inside marine reserves, the abundance, diversity, biomass, and size of fishes, invertebrates, and seaweeds usually increase dramatically. Species that are fished show the biggest changes, sometimes increasing 10 or 20 times in marine reserves. These outcomes are consistent across different habitats in tropical and temperate waters. Some species and habitats take many years—even decades—to respond, and the benefits can be wiped out in 1 to 2 years if the area is reopened to fishing.

Marine reserves support many ecosystem services, such as recycling of nutrients and protection of the coast from erosion, which are vital for the well-being of people living near marine reserves. The ecosystem in a marine reserve may withstand climate change and other environmental stresses better than altered ecosystems outside. Marine reserves provide a baseline for understanding how human activities affect other parts of the ocean, and they can protect places in the ocean with cultural and spiritual significance.

## Marine Reserves Are Only Part of the Solution

Marine reserves lead to different outcomes than traditional management approaches because they can protect a wide range of animals, plants, and habitats within a specific area. However, other management practices, such as quotas and gear restrictions, are necessary for sustainable fisheries outside marine reserves. In practice, marine reserves require complementary management tools because marine reserves cannot protect against all types of human impacts affecting the ocean. Additional impacts, such as pollution and climate change, must be addressed in other ways. Marine reserves are best viewed as an important tool, but not the only tool, to protect the health of the ocean.

*Photos, top to bottom: Robert Schwemmer, Freya Sommer, Steve Lonhart, U.S. Geological Survey, Jiangang Luo*

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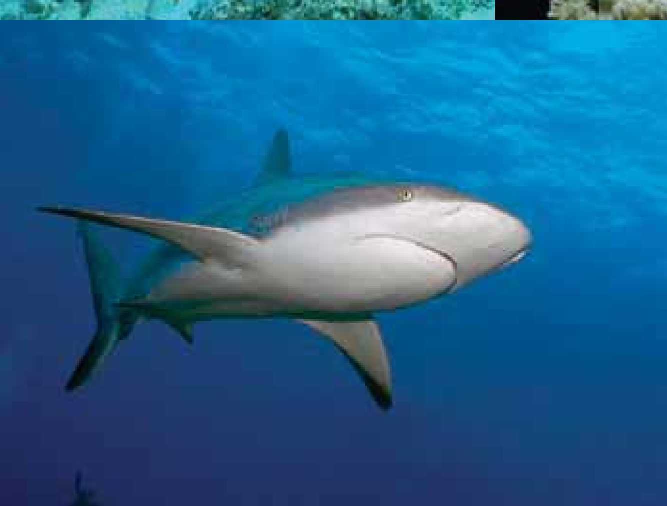



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